


Effects of Climate-Smart Agriculture Technologies on Maize-Common Bean Intercrops Growth and Yield Performances in Smallholder Farmer's Fields in Semi-Arid Areas, Tanzania

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Abstract

Climate-Smart Agriculture Technologies (CSATs) offer promising solutions to improve climate resilience and productivity among smallholder farmers. From 2022 to 2024, a study was conducted in semi-arid areas of Tanzania to evaluate selected CSATs, including a drought-tolerant maize variety (DTMV), an early-maturing bean variety (EMBV), and farmyard manure (FYM), compared to local varieties under traditional farmer practices (FPs). Using the Triadic Comparison of Technology (Tricot) method across 135 farms, treatments were assigned in incomplete randomized sets. Data were analyzed using ANOVA and the Plackett-Luce model. Results indicated that integrating improved varieties with FYM significantly boosted yields. The highest combined maize and bean yield was obtained from the T105 + TARI B6 treatment (4.809 ± 1.034 tons/ha), followed by T105 + Selian 13 (4.788 ± 0.991 tons/ha) and T104 + TARI B6 (4.56 ± 0.270 tons/ha). In contrast, traditional practices without FYM, such as Msituka + Bjesca (local checks), yielded significantly less (2.866 ± 0.726 and 2.705 ± 0.687 tons/ha). Further, treatments responded significantly to spacing and FYM ($P < 0.001$), with wider spacing increasing maize yield to 4.978 tons/ha, while bean yield was slightly higher at 75×30 cm (0.5485 tons/ha) than wider spacing (0.5456 tons/ha). The net gain in maize yield compensated for the slight bean difference, resulting in higher overall productivity. These findings emphasize the importance of CSATs, par-

ticularly improved crop varieties combined with FYM in enhancing yield and resilience to climate variability. The study recommends the adoption of these practices by smallholder farmers in semi-arid Tanzania as an effective strategy for climate change adaptation.

Keywords

Climate-Smart Agriculture, Intercrops, Farmyard Manure, Improved Varieties, Tricot

1. Introduction

Maize (*Zea mays L*) and common bean (*Phaseolus vulgaris L.*) are important staple food crops worldwide [1]-[3]. In Tanzania, maize is grown nearly at every corner [4], whereas common bean is mostly grown in the Northern, Southern highland, Western and Lake zones [5]. The demand for these crops has been increasing due to an increase in the human population, which has not kept pace with their production under climate change conditions [6] [7]. Thus, food insecurity has remained high in Sub-Saharan Africa (SSA) since 2000, when the United Nations (UN) published its Millennium Development Goals and the Sustainable Development Goals [7]-[9].

In particular Tanzania, agriculture is an important catalyst for economic growth, poverty alleviation, and food security [5] [10]. However, maize and common bean have been grown mostly in small-scale farming, and it has been challenged by climate change effects [1] [2] [11]. The climate change effects, put pressure on smallholder farmers to adopt proper production technologies [11]-[13]. The earlier studies clearly demonstrated the role of better climate-smart agriculture (CSA) technologies such as good quality seeds and proper management in boosting climate resilience [14]-[16]. Despite the importance of CSA to sustain agriculture production, there has been limited knowledge, awareness and low adoption of CSATs for better smallholder farming systems [17]-[20]. However a significant barrier to revealing the potential of CSATs has been limited knowledge of improved CSATs [21] [22]. The crop yields apart from the varieties as well as the CSA field management technologies, also depend on soil qualities [4] [23]. Therefore, the research envisioned to use the Triadic comparison of technologies (Tricot) as an approach and method which puts forward the evaluation of technologies in the hands of farmers [24].

The CSA was introduced in 2010 as a concept to orient agriculture towards a world acknowledging the changing climate [22] [25] [26]. The concept seeks to increase agricultural productivity and improve food security while adapting to and mitigating the impacts of climate change [27]. In Tanzania, CSA is gaining recognition as an important strategy for addressing the challenges of food security and climate change [25] [28] [29]. The government of Tanzania has made efforts

to promote CSA practices, including the integration of climate-resilient technologies and management practices in agriculture, such as conservation agriculture, agroforestry, and water harvesting [21] [28]. The government has also encouraged the use of improved crop seeds and other inputs that are adapted to the changing climate conditions [2] [15]. However, the implementation of CSA practices in Tanzania has been hindered by several factors, including a lack of awareness and information among farmers, limited access to finance, and weak extension services [21]. In addition, the adoption of CSA practices is often slowed by the lack of reliable and consistent support from the government and other stakeholders [6] [12] [25] [28]. Despite these challenges, there is potential for CSATs to contribute to sustainable agricultural development and food security in Tanzania [25] [30].

The intercropping of maize and common beans, the use of improved drought tolerance, early maturing, high-yielding seed varieties, and application of manure are the most commonly used CSA technologies by smallholder farmers in SSA [3] [31]. In developing a feasible and economically CSATs, viable intercropping system, planting patterns of the compatible crops are an important approach for enhancing system productivity [27] [32]. According to estimates, agricultural intensification alone may boost crop production in underdeveloped nations by 80% [33]. The rational use of land resources is essential to maize and common bean production [2]. However, efforts to target new technology in the particular biophysical circumstances in which smallholder farmers work are undermined by limited CSATs recommendations for semi-arid environments [34].

2. Materials and Methods

2.1. Description of the Study Location

The study was conducted in three districts: Babati (Manyara region), Kondoa (Dodoma region), and Singida Rural (Singida region), which are among the focus areas of the Agriculture and Fisheries Development Programme (AFDP) for the 2020-2026 period. This programme, funded by the International Fund for Agricultural Development (IFAD), focuses on developing climate change adaptation technologies in the drier Agro-Ecological Zone (AEZ) of Tanzania's central mainland corridor as shown in **Figure 1**. The selected districts were representative of semi-arid agro-ecological zones of Tanzania. The rainfall and temperature in the study area are presented in **Table 1**.

Table 1. Geographical location and weather information of the study area.

Location	Geographical position		Mean annual rainfall (mm)	Mean annual temperature (°C)
	Latitudes	Longitudes		
Babati (Manyara region)	04° 24' 60" S	35° 49' 26" E	600 - 1020	15 - 26
Kondoa (Dodoma region)	04° 54' 23" S	35° 46' 47" E	500 - 800	16 - 28
Singida Rural (Singida)	04° 63' 25" S	34° 95' 07" E	250 - 600	18 - 30

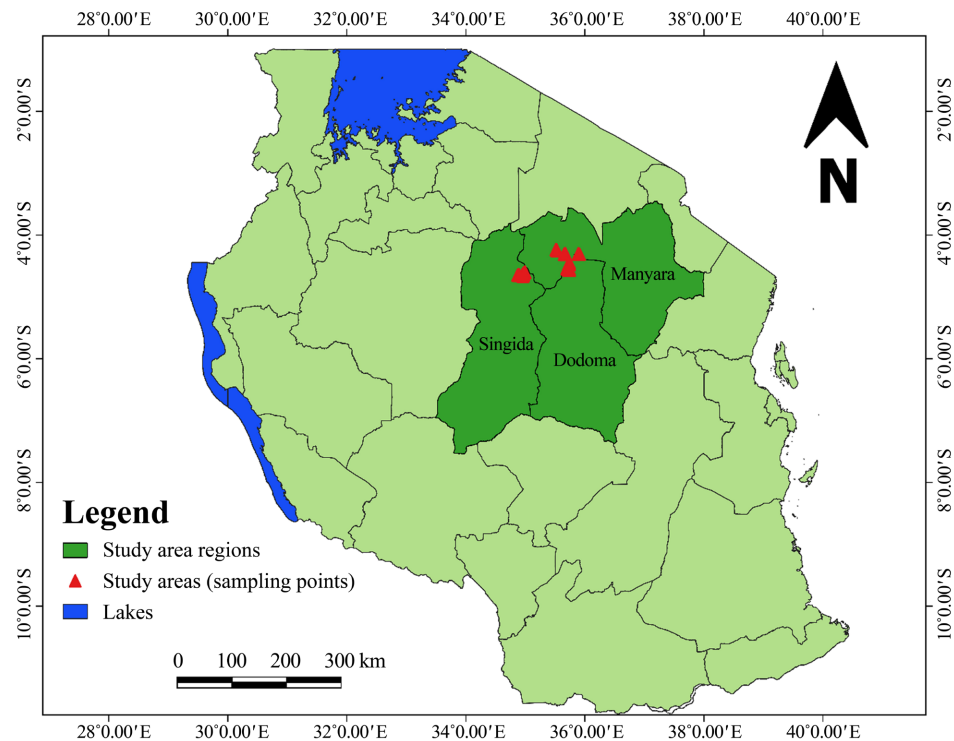


Figure 1. Map of Tanzania showing the study area.

2.2. Experimental Design, Layout and Planting

To assess the effectiveness of CSA technologies on maize and common bean intercropped, the study used the TRICOT approach [24] [35]. This is a farmer-centered, on-farm participatory research method (Figure 2), explaining that (A) trials are designed on ClimMob (<https://climmob.net/>) following a trial protocol derived from the target technologies profile under testing [36]. (B) Technology options (varieties, management practices among others), the selection was based on the aims of the experiment. (C) Sets of three technology options are assigned randomly as incomplete blocks from a broader set of technology packages. Field agents denoted (D) register participants on ClimMob and distribute the trial packages for farmers, the identifiable data (name, age, village, district, GPS) are recorded using Open Data Kit (ODK). (E) Participants guided by researcher and extension agent establish the experiment in their own farm and evaluate list of traits as per trial protocol (e.g., growth parameters, plant height, pest and disease resistance, drought tolerance, yield, etc.) using “tricot rankings” by indicating the option with best performance (1st in the ranking) and the option with worst performance (3rd in the ranking) for the given trait. The 2nd place in the ranking is added to the option not mentioned as best or worst for the given trait. (F) Participants’ assessments are registered using ODK, sent to the ClimMob platform, and aggregated for data analysis and production of automated reports [24]. This participatory approach enhanced scalability and relevance by placing farmers at the center of the research process.

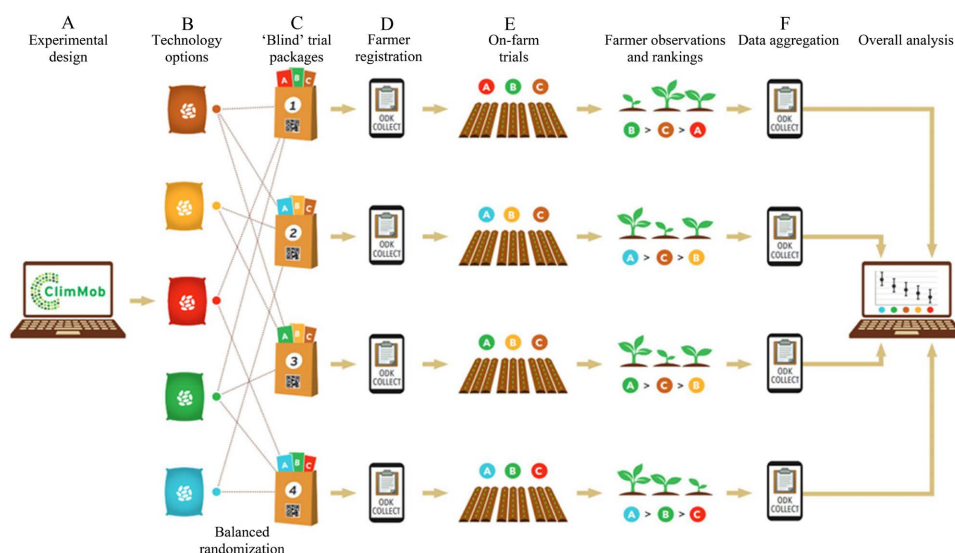


Figure 2. Overall Tricot approach trial design [37].

Table 2. Farmer participants.

Region	District	Ward	Village	Sample size
Manyara	Babati	Galapo	Hallu	15
		Dareda	Bermi	15
		Riroda	Riroda	15
Dodoma	Kondoa	Bereko	Bereko	15
		Salanka	Lembo	15
		Kikilo	Ororimo	15
Singida	Singida Rural	Merya	Mvae	15
		Mwasauya	Mdilu	15
		Ikhanoda	Msimihi	15
Total				135

A balanced incomplete randomized block design was used to plant the trials, with 135 farmer sites serving as blocks. **Table 2** shows the number of farmers who participated in the Tricot experiment per each village following the use of the formula below as indicated in equation 1.

$$\text{Equation: } n = \frac{N}{1 + Ne^2} \quad (1)$$

where:

n = sample size,

N = population size,

e = sampling error 5 percent [38].

Therefore, having the number of participants, allowed to assign treatments for evaluation. A total of 15 treatments, thus $\frac{15}{3} = 5$ sets of the treatments, that as-

signed (replicated) to 135 of the project participating farmers (blocks)

$\frac{135}{5} = 27$ replicates, with three (3) entries as test packages of technologies in each block as it was recommended by [39].

2.3. Experimental Treatments and Randomization

The CSATs such as farmyard manure (FYM), flat cultivated fields devoid FYM and farmers' field management techniques (FP) were used as the field management techniques as shown in **Table 3**.

Table 3. CSATs treatment description and field management techniques.

Treatment Code	Field Management Technique
FYM	Farmyard manure application
No FYM	Flat cultivated field (No FYM)
FP	Farmers' practice (as control)

The study focused on the intercrop sets made up of drought tolerant maize (DTMV) and early maturing common bean (EMCBV) varieties, as well as a set of known and available local check maize and common beans varieties. The treatments were randomized and assigned into incomplete randomized block designs (RCBD) as shown in **Table 4**.

Table 4. The CSATs treatments randomization.

With FYM-P1	Without FYM-P2	Farmer practice (FP)-P3
(DTMV1 + EMBV1) X P1	(DTMV1 + EMBV1) X P2	(DTMV1 + EMBV1) X P3
(DTMV1 + EMBV2) X P1	(DTMV1 + EMBV2) X P2	(DTMV1 + EMBV2) X P3
(DTMV2 + EMBV1) X P1	(DTMV2 + EMBV1) X P2	(DTMV2 + EMBV1) X P3
(DTMV2 + EMBV2) X P1	(DTMV2 + EMBV2) X P2	(DTMV2 + EMBV2) X P3
(LCMV + LCBV) X P1	(LCMV + LCBV) X P2	(LCMV + LCBV) X P3

Whereby;

CSA seed varieties for maize include: DTMV₁ for maize variety 1, DTMV₂ for maize variety 2, and LCMV for maize local check; CSA seed varieties for common beans: EMBV₁ for beans variety 1, EMBV₂ for beans variety 2, LCBV for beans local check.

The CSA management practices (P) under maize-common bean intercrops include: P1 with Farmyard Manure (FYM); P2 without farmyard manure (FYM); P3 farmer practice (FP).

2.4. Data Collection and Analysis

Specific growth stages (GS) of maize and common bean were recorded during the

growing season. The data collected from sole maize, sole common bean and maize-common bean intercrop plots during main and short rain planting seasons were analyzed using a combination of mixed models and analysis of variance (ANOVA) [40] [41].

In a mixed model framework, genotypes, cropping systems, spacing and FYM application were treated as fixed effects while farm (location) and season were treated as random effects [42]. This was to account for natural variability across the farmer-managed plots and seasonal weather conditions, enhancing the generalizability of the results [43]. The random structure addressed spatial and temporal heterogeneity that may otherwise bias fixed effect estimates [44].

The coding of experimental treatments included combinations of sole maize, sole common bean, and maize-common bean intercrops, across different spacing levels and FYM application rates. This structure allowed the testing of the hypothesis that inter-row spacing and FYM rates significantly influence the yield of maize-common bean intercrops in semi-arid regions of Tanzania.

To test the assumptions of normality and homogeneity of variances, the Shapiro-Wilk test and Bartlett's test were applied to the residuals before conducting ANOVA. The validity of the mixed model approach relied on the fulfillment of these assumptions. Additionally, multiple linear regression was performed with grain yield as the response variable and agronomic indicators such as cob and pod weight, total biomass, and plant population as explanatory variables, to assess their contributions to yield.

All statistical analyses were performed using GenStat Discovery Edition 21. For the maize-common bean intercrop data, a 3-way ANOVA was conducted using the model shown in Equation 2:

$$\text{Equation: } Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \varepsilon_{ijk} \quad (2)$$

where:

Y_{ijk} = observed value in the ijk th treatment combination;

μ = overall mean;

$\alpha_i, \beta_j, \gamma_k$ = main effects of variety, spacing, and FYM;

$(\alpha\beta)_{ij}, (\alpha\gamma)_{ik}, (\beta\gamma)_{jk}$ = two-way interactions;

$(\alpha\beta\gamma)_{ijk}$ = three-way interaction;

ε_{ijk} = random error.

The 3-way ANOVA was appropriate because it allowed simultaneous evaluation of the main and interaction effects of three agronomical relevant factors—variety, spacing, and FYM application—on intercrop performance. This was critical for uncovering synergies or trade-offs essential for CSA recommendations in resource-constrained, semi-arid environments.

For the sole common bean data collected during the short rainy season, a 2-way ANOVA was conducted as shown in Equation 3:

A 2-WAY ANOVA was used for the data of common bean collected during the short rainy season and the factor effects model (Equation 3) was:

$$\text{Equation: } Y_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ij} \quad (3)$$

where:

Y_{ij} = observation in the ij^{th} treatments;

μ = overall mean;

α_i, β_j = main effects of spacing (S) and farmyard manure (FYM);

$(\alpha\beta)_{ij}$ = interaction effect between S and FYM;

ε_{ij} = random error associated with the observation in the ij^{th} factors.

Similarly, for sole maize, a 2-WAY ANOVA was applied (Equation 4) as follows:

$$\text{Equation: } Y_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ij} \quad (4)$$

where:

α_i , and β_j = main effects of spacing (S) and farmyard manure (FYM) application.

Soil data collected at the end of each harvest (2023 and 2024) were analyzed using one-way ANOVA to compare soil fertility indicators across intercropping systems and sole cropping with different FYM rates, using Equation 5:

$$\text{Equation: } Y_i = \mu + \alpha_i + \varepsilon_i \quad (5)$$

where:

Y_i = Value of soil nutrient in the i^{th} intercropping system;

μ = overall mean;

α_i = effect of the intercropping system;

ε_i = random error.

All significance tested were evaluated at the 95% confidence level ($P = 0.05$). Post hoc comparisons were made using Tukey's test to determine statistically significant differences among the treatment means [41] [45].

Evaluation of land equivalent ratio (LER)

The Land Equivalent Ratio (LER) was a crucial index used to evaluate the productivity and efficiency of intercropping systems compared to sole-cropping [31] [46]. It indicates how much land would be required under sole cropping to achieve the same yields obtained in an intercrop. An LER greater than 1.0 suggests a yield advantage for intercropping, meaning the system uses land more efficiently. The evaluation of the productivity of intercropping systems relative to monoculture was done using the LER, of each intercropping system was obtained by summing up the relative yields, that is, yields (ton/ha) of maize and beans in the same intercropping system were divided by that of maize and beans in sole cropping in order to give relative yields and then added together to give LER as shown (Equations 6, 7 and 8).

The general formula for calculating LER in a two-crop system was:

Assumption: LEF = PLER

$$\text{Equation: } \text{LER} = \text{PLER maize} + \text{PLER common bean} \quad (6)$$

$$\text{Equation: } \text{PLER maize} = \text{Yield of maize in intercrop} \quad (7)$$

Yield of sole maize

$$\text{Equation: PLER common bean} = \text{Yield of common bean in intercrop} \quad (8)$$

Yield of sole bean

Similarly, the data set was subjected to analysis of variance (ANOVA) using GenStat Version 21 as well the R-software using the following statistical model (Equation 9) was

$$\text{Equation: } Y_{ij} = \mu + T_i + B_j + e_{ij} \quad (9)$$

where:

Y_{ij} = observation i^{th} of the treatments and j^{th} = blocking factor;

μ = overall mean;

T_i = treatment effects;

B_j = effect in block e_{ij} .

The treatment means for the different parameters were separated using Tukey HSD test at 0.05 level of significance.

3. Results and Discussions

3.1. Analysis of Variance of CSATs for Growth and Yield Performance

An ANOVA was performed to test the hypothesis that at least one technology or treatment had a significantly higher performance across key traits compared to the others. The results, illustrated in **Figure 3**, showed that for most traits, the p-values were less than 0.05, confirming that the performance differences observed among the items were not due to random chance. This suggests that at least one item in the set performed significantly better in traits such as cob size, plant vigor, and pod number. These findings confirm that the adoption of improved varieties and management practices can lead to significant performance enhancements under semi-arid conditions, a critical consideration for increasing resilience to climate variability.

Traits such as cob size for maize and pod count for common beans had the most significant variance across treatments, which directly correlates with yield potential and marketable produce. To assess which traits most strongly influenced farmers' overall preference, a Kendall tau correlation analysis was conducted and among all traits evaluated, Cob size [Maize harvest yield data]' exhibited the strongest correlation with 'Overall Preference', with a Kendall tau coefficient of 0.41, indicating a moderate positive association.

The results imply that larger cob size was a strong determinant of technology preference by smallholder farmers, likely due to its direct impact on food security and market value. On the other hand, the trait 'Germination (Agronomic performance)' had the weakest correlation with overall preference, with a Kendall tau of 0.01, suggesting that while germination is important for stand establishment, it may not heavily influence farmers' ultimate selection decisions, especially if later-stage performance (e.g., yield, cob size) is strong. These findings provide empirical support for the effectiveness of CSATs in improving key agronomic traits that

influence both biological yield and farmers' perceptions of performance as reported by [26]. The results also emphasize the importance of targeting traits that are both statistically superior and practically valued by end-users [47]. The strong performance of certain improved maize and bean varieties, especially in cob size and pod number, reinforces their suitability for scaling in semi-arid zones.

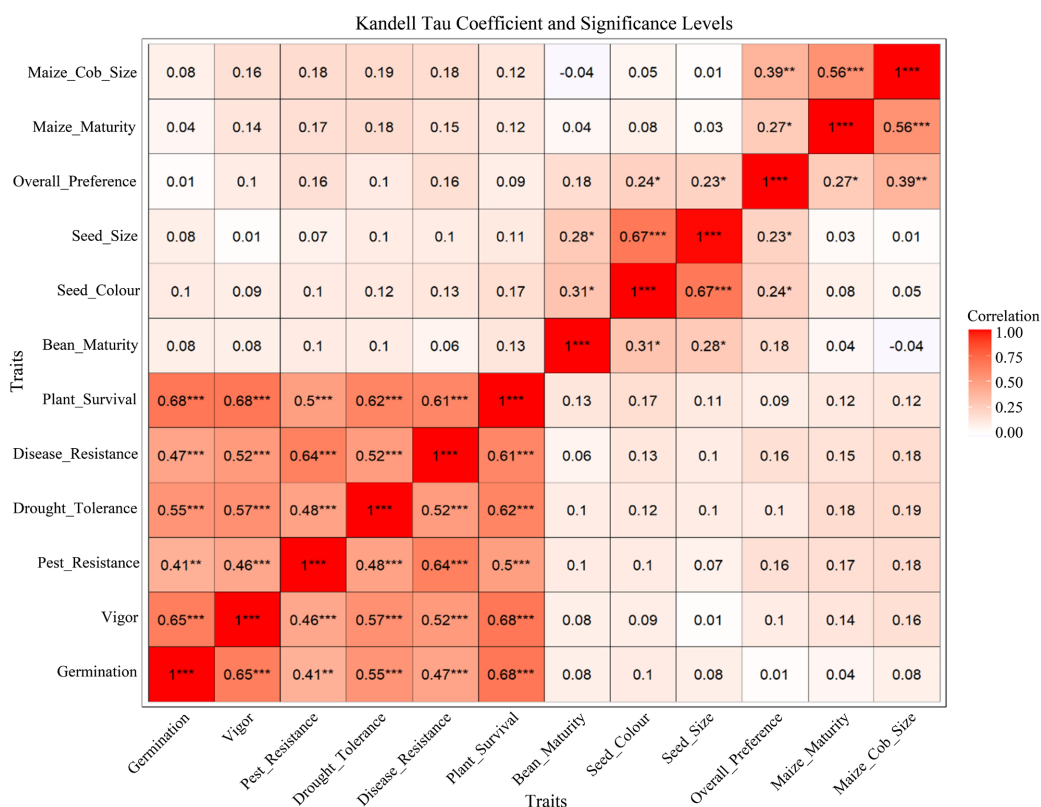


Figure 3. The Kendall tau coefficient between 'Overall Preference' and the other trait.

3.2. The Growth and Yield Trait of Maize and Common Bean Genotypes

The log-worth values by trait for each technology tested in this experiment are illustrated in **Figure 4**. This graphical representation provides an intuitive assessment of how different maize and common bean varieties performed relative to the local checks the SITUKA (maize) and JESCA (common bean). The figure displays log-transformed worth values that quantify the likelihood of each technology outperforming the local checks on a trait-by-trait basis. The log-worth parameter is a statistical transformation of the performance probability that aids in distinguishing superior and inferior entries across multiple traits. A log-worth greater than 0 (blue bars in the chart) indicates that a given variety has a statistically higher chance of surpassing the performance of the local checks for that particular trait. Conversely, a log-worth less than 0 (red bars) denotes underperformance relative to the checks. Therefore, the approach was useful for visualizing not only the general performance trend of an item but also the variability in its performance across different agronomic parameters such as cob size, pod number, biomass yield,

plant vigor, and pest resistance. For instance, technology with consistent positive log-worth across multiple traits can be considered highly promising candidates for broader dissemination in similar agro-ecological zones.

In this experiment, several improved maize and bean varieties displayed superior log-worth values in traits closely associated with yield, including cob size, grain weight, and pod count. These traits are crucial for determining productivity and farmer satisfaction. Notably, varieties such as T105 (maize) and TARIB6 (common bean) exhibited consistently high log-worth scores across multiple traits, suggesting their robust adaptation to the semi-arid environments under evaluation. The study also applied stratified performance analysis reinforces the value of combining statistical modeling with field-level observations to support decision-making in technologies selection. The log-worth analysis complements the ANOVA and Kendall tau results by adding a probabilistic dimension to performance.

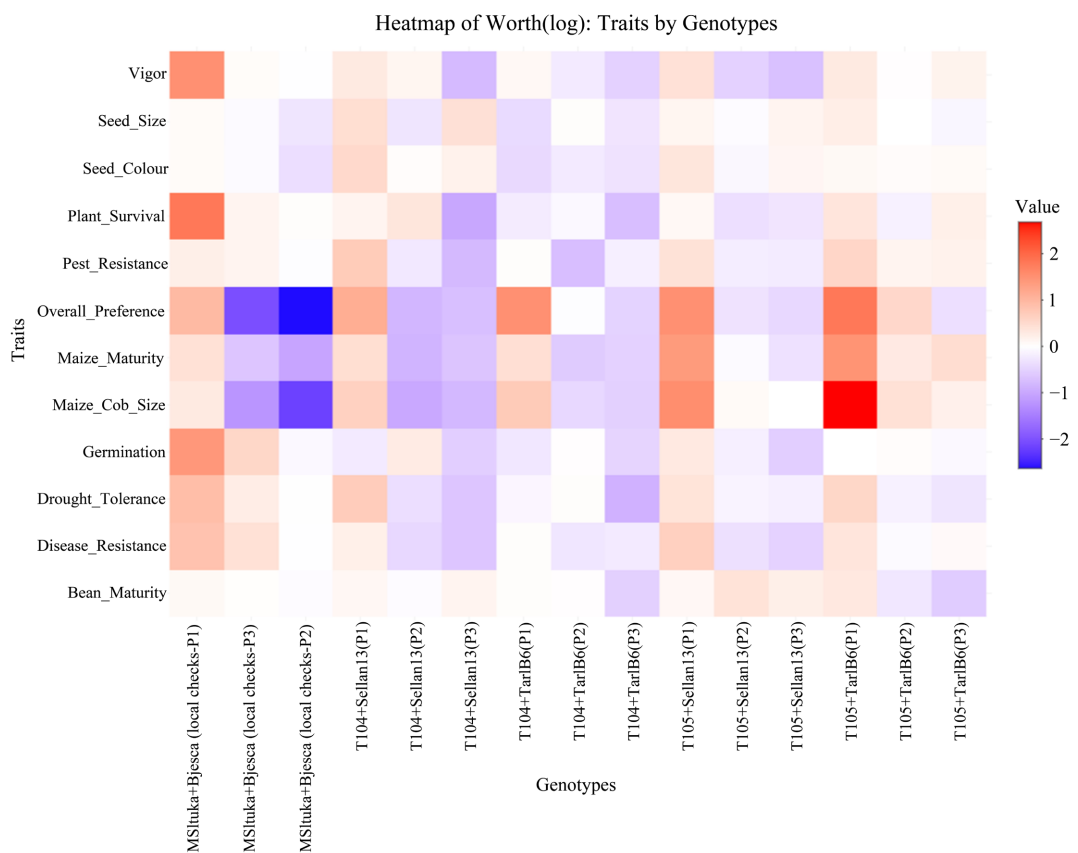


Figure 4. Item performance by trait.

Reliability (probability of outperforming a check) estimates based on worth estimates from PL model were presented in **Figure 5**. Reliability measures the precision of estimated worth and the potential response to selection compared to a check. It is a breeding metric proposed by [48]. The reliability estimates were calculated considering the Overall Preference with Msituka + Bjesca (Local checks)

as the check item. The blue vertical line set to 0.5 indicates a threshold from where a given item presents a potential probability in outperforming the check (reliability > 0.5).

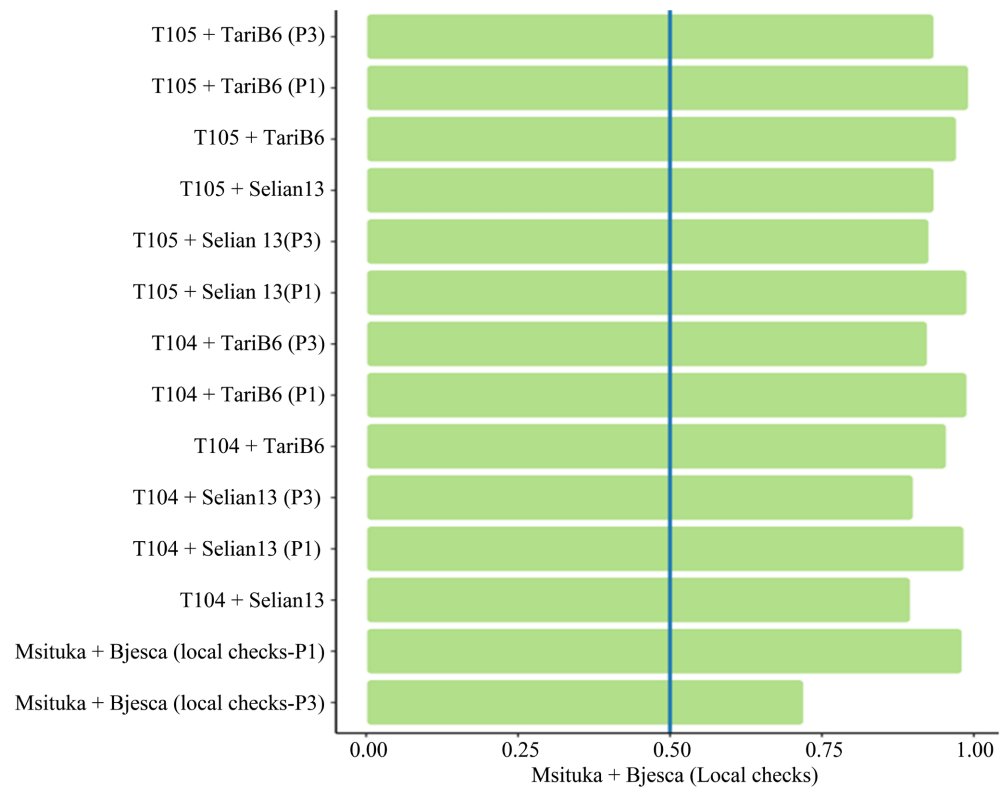


Figure 5. Reliability and probability of outperforming of tested items versus the local-check.

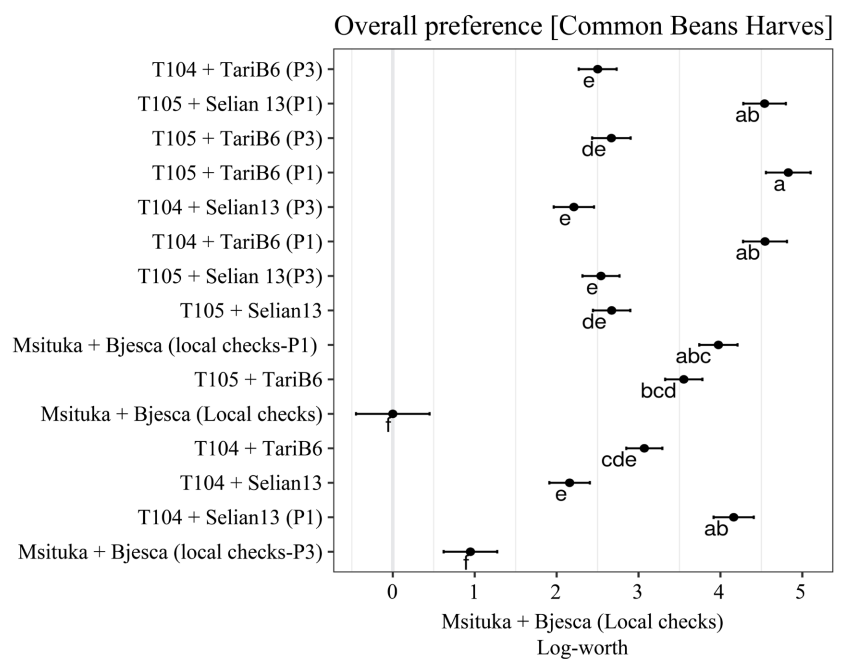


Figure 6. Plackett-Luce Model estimates (log-worth) of tested items for the reference trait.

The estimated log-worth for the ‘Overall Preference’ reference trait as shown in **Figure 6**, the purpose was to be able to distinguish the item with the superior performance. Mean separation analysis was also conducted to indicate which item is significantly different (or similar). When items have at least one letter in common, there is not enough evidence from the trial to be confident about their relative order with $p\text{-value} = 0.05$. The Overall Preference’ assessed in this study trials and the intervals were based on quasi-standard errors.

3.3. The Effects of Application of FYM on Yield Trait of Maize and Common Bean in Semi-Arid Areas of Tanzania

The results showed that DTMV and EMBV intercrops grown and managed using application of FYM resulted into higher yields of both maize and common beans T105 + Tari B6 (PI) in ton ha^{-1} at (4.809 ± 1.034) ; followed by T105 + Selian 13 (PI) in ton ha^{-1} at (4.788 ± 0.991) and T104 + TariB6 (P1) in ton ha^{-1} at (4.56 ± 0.27) . The trials managed with farmer practices (FPs) without applications of FYM yield less of both maize and common beans Msituka + Bjesca (local checks-P3) in ton ha^{-1} at (2.866 ± 0.726) , Msituka + Bjesca (local checks-P2) in ton ha^{-1} at (2.705 ± 0.687) and T104 + Selian13 (P3) in ton ha^{-1} at (2.156 ± 0.804) . These findings are in line with the study by [49], the results showed that maize-bean intercropping with application of manure enhanced the resilience of the drought-tolerant bean genotypes giving a 44.4% yield increase as compared with the intercropping of maize and common beans without application of FYM. The study concluded that the improved DTMV and EMBV managed with FYM as significant effects in climate resilience and increase yields of maize and common beans as the results shown in **Figure 7**.

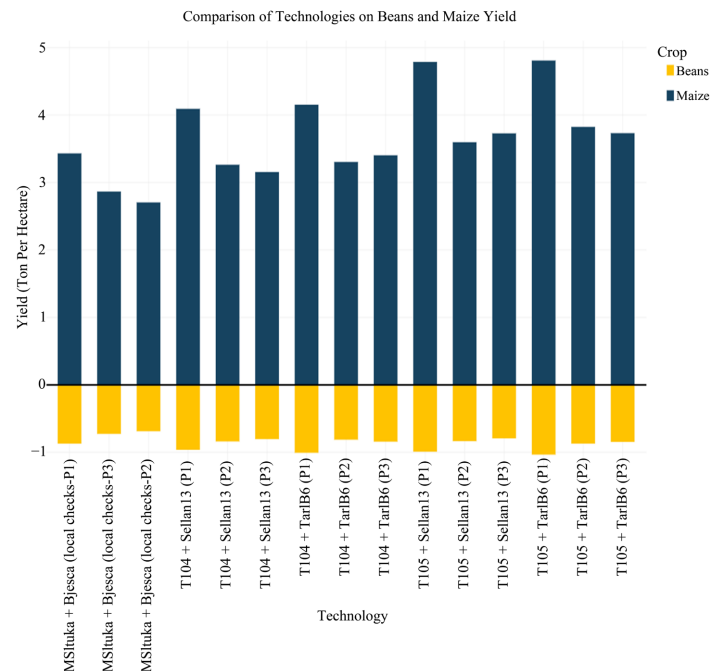


Figure 7. Effects of CSATs on maize and common bean yields.

3.4. Gender-Specific Preferences for CSATs in Semi-Arid Areas Tanzania

The evaluation of gender in maize-bean intercropping reveals distinct priorities between male and female farmers [22] [36] [47]. Understanding these differences was crucial for developing and promoting agricultural practices that were both effective and equitable [47]. The study evaluated the gender preferences on twelve (12) traits which were evaluated which were the bean maturity, disease resistance, drought tolerance, germination, maize cob size, maize maturity, pest resistance, plant survival, seed color, seed size, and vigor as shown in **Figure 8**. The results show that women prioritized the traits that enhance household food security and ease of processing. This includes preferences for seed color and size, which can affect culinary qualities and marketability [24] [39]. The results also show that female farmers targeted characteristics based on both agronomic and post-harvest grain attributes to ensure the sustainability of household food intake as shown in **Figure 8** which also reported by [50]. The women have shown a preference to drought tolerance, and resistance to pests. To adapt to climate variability, women were preferred the use of improved seeds, aiming to mitigate risks associated with unpredictable weather patterns [39] [47].

The men typically prioritize traits that maximize economic benefits, such as larger maize cob size and higher overall yields. The men decisions were driven by market-oriented goals thus, were more focusing on technologies that can significantly boost production as also reported by [47]. Generally, both male and female farmers valued traits that confer resistance to diseases and pests, recognizing the importance of plant survival and vigor in ensuring consistent yields [50] [51]. Given the increasing challenges posed by climate change, drought tolerance is a universally desired trait among farmers to safeguard against drought. These gender-specific preferences highlight the need for inclusive agricultural research and extension services that consider the distinct priorities of male and female farmers [47]. By addressing these differences, interventions can be better tailored to meet the diverse needs of farming communities, leading to more sustainable and equitable agricultural development [51].

3.5. Baseline Soil Fertility before FYM Application

Baseline soil fertility analysis conducted before FYM application in 2023 indicated low levels of organic matter and key nutrients. The average organic carbon content was 2.24%, and total nitrogen averaged 0.15%. Phosphorus levels ranged from 6.2 to 8.5 mg/kg, and exchangeable calcium and magnesium were generally below optimal levels, with mean values of 6.1 and 2.2 CmolKg^{-1} , respectively. These values highlight the poor fertility status typical of semi-arid soils and provide context for the substantial improvements observed after FYM application, particularly in the 8 t/ha treatment. The increase in soil organic matter and nutrient availability demonstrates the importance of organic amendments for sustainable soil fertility management [20] [52].



Figure 8. Gender preferences for CSATs.

3.6. Land Equivalent Ratio (LER)

Based on the experimental results, the best-performing intercropping system was SP50 × 50 spacing with FYM at 8 t/ha. The corresponding yields were: the intercrop maize yield 5.416 ton ha⁻¹, the intercrops bean yield: 0.5356 ton ha⁻¹, and the sole maize yield about 4.978 ton ha⁻¹ and the sole bean yield 0.5485 ton ha⁻¹.

The Partial LERs were calculated as:

PLER for maize: $5.416 / 4.978 = 1.088$

PLER for common bean: $0.5356 / 0.5485 = 0.977$

Thus, the total LER: $1.088 + 0.977 = 2.065$

This LER value indicates that the intercrop system with SP50 × 50 spacing and 8 t/ha FYM application is 107% more efficient in land use than growing maize and beans separately on the same area. These findings confirm the high potential of CSAT intercropping approaches for improving productivity and land-use efficiency in semi-arid environments as were reported by [31] [53].

3.7. Economic Feasibility of CSAT Recommendations

To evaluate the economic feasibility of the CSAT recommendations, a cost-benefit analysis was conducted comparing input costs and the additional value of grain yield under different manure rates and spacing. The highest-performing treatment combination (FYM at 8 t/ha and 50 × 50 cm spacing) resulted in maize and bean yields of 7367 kg/ha and 1040 kg/ha, respectively. Assuming average farm-gate prices of 500 TZS/kg for maize and 1500 TZS/kg for beans, the gross income per hectare amounts to 3,683,500 TZS (maize) and 1,560,000 TZS (beans), totaling approximately 5,243,500 TZS/ha. Input costs for 8 t/ha of FYM application were estimated at 800,000 TZS/ha (including transport and labor), while labor and seed costs amounted to approximately 600,000 TZS/ha. This gives a net return of approximately 3,843,500 TZS/ha, confirming the economic viability of this package under semi-arid conditions also were reported by [26] [54] the benefits of the use of CSAT.

3.8. Limitations of the Study

Despite the robust experimental design and analysis, several limitations may have influenced the observed yield differences. Firstly, variability in rainfall across the growing seasons introduced inconsistencies in crop performance, especially in water-limited environments. Secondly, heterogeneity in farmer management practices including planting time, weeding frequency, and fertilizer application may have introduced uncontrolled variability across trial sites. Additionally, other potential confounders such as differences in soil fertility, pest pressure, and access to inputs could not be fully standardized across the decentralized on-farm trials. While efforts were made to account for these factors through the inclusion of farm and season as random effects in the statistical model, their residual influence on yield outcomes cannot be entirely ruled out. These limitations highlight the importance of cautious interpretation and the need for further controlled trials to complement farmer-participatory evaluations.

4. Conclusion and Recommendations

The findings of this study have revealed important options for climate resilience as climate change causes a major threat to smallholder farmers' agricultural production and food security in semi-arid areas, Tanzania. The CSATs were crucial in addressing the potential impacts as they increase maize and common bean productivity and hence improve food security. While previous research mostly focused on the usage of single CSAT such as intercropping, this study used multiple combinations of CSATs which were participatory evaluated by researchers and smallholder farmers. The study identified that climate resilience was influenced by the use of improved crop varieties and crop management practices. The use of DTMV and EMCBV was significant for climate resilience under a smallholder intercropping system in semi-arid areas of Tanzania. The primary findings demonstrate that CSATs include drought-tolerant maize varieties (DTMV) and early maturing bean varieties (EMBV). The study also highlights the pivotal role of the TRICOT participatory evaluation method in accelerating the adoption of CSATs.

The evaluation of soil quality under farmyard manure (FYM) application in smallholder farmer fields in semi-arid areas of Tanzania demonstrated the vital role of organic inputs in sustaining soil health and enhancing agricultural productivity. The results revealed that FYM significantly improved key soil quality parameters, including soil organic matter, structure, moisture retention, and nutrient availability. These improvements are crucial in water-limited environments where soil degradation and nutrient depletion are major constraints to crop production. Compared to traditional practices that often rely solely on mineral fertilizers or neglect soil fertility management, the application of FYM contributed to a more balanced and resilient farming system. Furthermore, the use of FYM was associated with increased crop yields and improved soil physical properties, underscoring its potential as a climate-smart soil fertility strategy. Therefore, promoting the use of FYM not only supports sustainable intensification but also enhances the adaptive capacity of smallholder farmers facing increasing climate variability in semi-arid regions of Tanzania.

Based on the analysis and findings of the study, I wish to make the following recommendations.

- i. Promote integrated CSAT packages: Agricultural extension programs should prioritize the promotion of combined CSATs such as improved varieties, intercropping, timely planting, and water conservation techniques over the application of single practices. The participatory approach used in this study showed that combinations of CSATs yield better results and are more readily adopted by farmers.
- ii. Strengthen participatory research and extension: Future CSAT interventions should be designed and implemented through participatory platforms involving researchers, extension officers, and farmers. This enhances rele-

vance, increases adoption, and fosters local innovation and ownership. The use of the participatory Tricot approach has shown promise in accelerating the adoption of new technologies by smallholder farmers.

- iii. Encourage widespread use of FYM: The findings confirm the effectiveness of farmyard manure in improving soil quality and crop yields under semi-arid conditions. Extension services should encourage its use as a low-cost, locally available, and sustainable soil fertility management practice. Thus, integrate organic with inorganic inputs: Where economically feasible, integrated soil fertility management (ISFM) combining FYM and minimal inorganic fertilizers should be promoted to balance short- and long-term productivity and resilience.
- iv. Supporting farmer training in composting and manure management: Capacity-building initiatives should equip farmers with skills in manure collection, storage, and application methods to maximize nutrient retention and reduce nutrient losses. Local bylaws or incentives could promote manure use and discourage burning or wastage.

Author's Contributions

K.G.M, M.P, M.I.A and M.A.T; Conceptualization and methodology, K.G.M, M.P, M.I.A and M.A.T; writing—original draft preparation, K.G.M, M.L.P, M.A and M.T; writing—review and editing, K.G.M, M.P, M.I.A and M.A.T; all authors have read and agreed to the published version of the manuscript.

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Data Available Statement

The datasets used and findings analyzed to support this study are available from the corresponding author, (K.G.M), upon reasonable request.

Conflicts of Interest

Authors declare no conflict of interest.

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